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A. F. Hooper

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AR-592-1-434

22 April 1963

SUBJECT: Interpretation of Radiographic Images of Nickel Foil Reinforced Resistance Spot Welds in Type 301 Stainless Steel

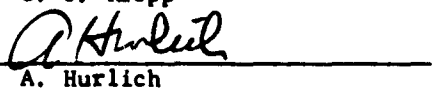
ABSTRACT: Several samples of nickel reinforced resistance spot welds in Type 301 stainless steel sheet were radiographed using a beryllium window tube. A few spot welds which were prepared for microscopic examination were chosen on the basis of dark internal X-ray images appearing within the weld image as well as some dark line images on the periphery of the spot weld. The spot weld samples were obtained from both fractured fatigue test specimens and unstressed weld test panels.

Microscopic examination of the spot welds indicate that the dark internal X-ray images and the dark peripheral line images represent the outline of the type of nickel enriched 301 weld nugget formed. The types of weld nuggets found include a ring or "dough-nut" weld, a letter "U" or horseshoe weld, and a type of weld nugget which is apparently an intermediate stage between a horseshoe weld and a "dough-nut" weld. The dark line X-ray image on the periphery of the nugget image could not be attributed to a void or crack on the basis of the microscopic examination conducted.

The ability of radiography to outline the nickel enriched weld nugget and to record the peripheral dark line image is probably a result of the difference in the radiopacity of the steel, the nickel foil, and the nickel enriched weld nugget.

As based on the present fatigue tests, the presence of the various types of incomplete weld nuggets illustrated in this report does not seem to have any deleterious effect on the fatigue life of the weld joints.

Prepared by 
C. J. Kropp

APPROVED BY 
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Chief of Materials and Structures Research

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AR-592-1-434

22 April 1963

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FROM: MATERIALS RESEARCH GROUP, Dept. 592-1

SUBJECT: Interpretation of Radiographic Images of Nickel Reinforced Resistance Spot Welds in Type 301 Stainless Steel

INTRODUCTION

The incorporation of nickel foil inserts between two sheets of 301 prior to resistance spot welding in Centaur Production assemblies and weld schedules has resulted in uncertainties in the radiographic interpretation of the weld images. The major difficulty is the interpretation of dark, irregular lines in the image of the weld, which seem to occur, at the present time, in the following gages: 0.010, 0.011 and 0.016 inch thick extra hard 301 sheet with 0.003 inch thick nickel foil inserts. Some images are detected within the circular weld image in the form of dark circles or irregular curves while other images appear to be dark lines on the inner periphery of the light halo image.

Since individuals in the radiographic laboratories, as well as the production inspectors, were not familiar with the significance of the images encountered, it was decided that the clarification of the problem would be handled in the following manner. Reproductions of radiographs illustrating typical irregular images in the weld image would be obtained along with photomicrographs of the corresponding cross-sectioned spot welds. The apparent cause of the images could then be observed.

Since it is entirely probable that additional types of questionable X-ray weld images may be detected, it is suggested that the photographs presented in this report be used to establish a reference book containing various types of X-ray weld images correlated with the factors causing them. If other types of weld images are found, supplementary illustrations will be distributed for inclusion in the reference book.

DISCUSSION

When the irregular X-ray images in nickel enriched resistance spot welds were first encountered in radiographs of productions welds, the first two interpretations were: 1) the spot welds contained internal cracks or branched porosity within the weld nugget or 2) since it was a known fact that the nugget microstructure, in some instances, has a "marble cake" appearance caused by the light and dark etching phases of the heterogeneous nugget, it was felt that the X-ray images brought

out this feature. The dark peripheral line image on the other hand was believed to be a crack at the weld nugget and nickel foil interface.

Since the irregular shaped internal images appeared to have neither sufficient density or fineness to be attributed to internal branched porosity as based on previous X-ray images presented in Report No. AR-592-1-374, it seemed feasible that either the heterogeneous microstructure or some other characteristic was being detected by radiography. The dark peripheral line image, however, could be attributed to cracks or sheet thinning since the density and width of the line images are very similar to the type caused by these two weld defects. The primary purpose of this investigation is to illustrate the cause of the irregular shaped X-ray images in nickel enriched resistance spot welds.

To determine the cause of the irregular X-ray images, several 0.011 and 0.016 inch thick 301 fatigue specimens containing a longitudinal weld joint with 0.003 inch thick nickel foil inserts were radiographed before and after testing. The resistance spot welds in the weld joints were made by using the weld schedule shown in Report No. AR-592-1-358. The 301 sheet material used to fabricate the fatigue specimens is identified as follows:

1) 0.011 inch thick, Heat No. J62879, Coil No. 19420, Spec. No. 0-71022
2) 0.016 inch thick, Heat No. 57860, Coil No. 14809, Spec. No. 0-71004

The spot welds investigated and presented in this report were obtained from two fatigue specimens which were tested at -423°F. One specimen, 0.011 inch thick 301, was stressed from 0 to 190 ksi, was found to leak after 1000 cycles and failed after 1007 cycles. The second specimen, fabricated from the 0.016 inch thick 301, was stressed from 0 to 160 ksi, leaked at 500 cylcles and failed after 539 cycles. These data are presented in another report (AR-592-1-412).

Since it would be advantageous to examine nickel enriched resistance spot welds in the as-welded condition, that is, welds which were neither fatigue tested or subjected to cryogenic temperatures, three 4 inch x 8 inch panels were spot welded using two sheets of the 0.011 inch thick 301 with 0.003 inch thick nickel foil inserts. The three sheets of each panel were joined with thirty-six spot welds on one inch centers using the same weld schedule as was used with the fatigue specimens. The panels were also radiographed with a beryllium window tube.

The X-ray films of both the fatigue specimens and the welded test panels were examined to choose spot welds which contained typical irregular X-ray images as encountered in production. In addition, some films were examined by personnel in the X-ray laboratory to choose spot welds which contain a dark line image on the inner periphery of the light halo image.

The photographic illustrations of the various X-ray weld images found in the spot welded samples are divided into two categories: 1) internal images and 2) peripheral dark line images.

Internal X-ray Images of Nickel Enriched Resistance Spot Welds

The resistance spot welds with the nickel foil inserts shown in Figures 1 through 8 were obtained from the weld joint of the 0.011 inch thick 301 fatigue specimen. To show the internal conditions of the spot welds to the best advantage, some of the spot welds were cross-sectioned, ground, and polished to the centerline of the weld nugget. The remaining spot welds were mounted, ground, and polished to show the nugget in a plan view which is similar to the image recorded on the radiographs. The grinding and polishing in the latter method is always performed on the doubler sheet and progresses in the direction of the nickel foil and test skin.

The second method, however, does not always result in a complete and true view of the nugget because the grinding and polishing of the sample must be stopped either before the nickel foil is reached or after its complete removal. A plan view thru any part of the nickel foil is not possible due to the soft and thin nature of the foil.

Even though a plan view does not always result in showing the complete weld nugget, the microscopic plan views shown in Figures 2 and 12A indicate the true outline of the nugget by the presence of the lighter etching area which includes portions of fused metal. A good plan view of a nugget is shown in Figure 6, which justifies the above statement that radiography is capable of detecting the true outline of a nickel enriched spot weld nugget. The photomicrographs of cross-sectioned weld nuggets shown in Figures 4 and 8 also substantiate the ability of radiography in detecting weld nugget shapes.

A "ring" or "dough-nut" weld is shown in Figures 2 and 4 while a heterogeneous weld nugget is shown in Figure 6. This type of nugget is evidently an intermediate step between a ring weld and a completely satisfactory nugget. An example of a complete nugget is shown in the radiograph in Figure 9 and the photomicrograph in Figure 10. It should be observed that no internal image exists in the radiograph of this spot weld.

An example of another intermediate stage of spot weld fusion is shown in Figures 11 and 12. This nugget is not a ring weld, but appears to be more like the letter "U" or a "horseshoe". The X-ray image (Figure 11) of this spot weld also illustrates the ability of radiography to detect the true weld nugget shape.

The photomicrograph shown in Figure 12A is a plan view of the weld at a stage where the outline of the fused horseshoe shape is not complete. The outline of the fused metal and the light etched area, however, indicates the entire horseshoe shape. This statement is substantiated by Figure 12B which shows the same weld, except that an additional 0.003 inch was removed by grinding and polishing. The outline of the fused metal matches perfectly with the X-ray image.

Dark Line Images on the Inner Periphery of the Light Halo Image

The radiographs shown in Figures 1, 3, 5, 7, 11, 13, 18, 23, and 26 illustrate the dark, peripheral line image which is recorded on X-ray film of the nickel enriched resistance spot welds. The photomicrographs of the corresponding cross-sectioned spot welds shows that thinning of the 301 sheets is not present in all of these spot welds. A previous report (No. AR-592-1-374), which presented similar illustrations of 301 resistance spot welds without the nickel foil inserts, confirmed the detection of sheet thinning by X-ray inspection.

Two spot welds shown in Figures13 thru 22 were removed from a weld test panel which was never stressed or subjected to cryogenic temperatures. Photomicrographs of the as-polished cross-sections clearly show that no cracks exist at or near the weld nugget. The as-polished sections were also included to answer the question of the black line at the nickel foil and nugget interface of an etched cross-section. This black line has been interpreted as a crack or break in the nickel foil. It will be observed that the dark line on the X-ray image is not caused by a crack, but represents the interface between two different metal phases. Since these spot welds are completely fused (not of the ring, horseshoe, or puckered type), it is believed that radiography is again detecting the outline of the nugget by means of the dark, peripheral line image.

Some thinning of the load sheet (test skin) is apparent in the two spot welds shown in Figures 23 thru 28. These two spot welds were removed from the unbroken end of a specimen which had been fatigue tested (LB5ON). When the dark line X-ray images of the above spots are compared to the images of the unstressed spots (Figures 13 and 18), it will be noted thatthe density and geometry of the images are very similar.

The final spot weld (shown in Figures 29 and 30) is included to illustrate the radiographic image and cross-section of a spot weld which leaked after fatigue testing. The interpretation of this X-ray image would be obvious, but it illustrates the fact that a crack would be recorded as a much finer line than the dark, peripheral line shown previously. It is anticipated that spot welds from tested fatigue specimens will eventually be found that contain only a partial fatigue crack. When such spot welds are found, the radiographs and photomicrographs of the welds will be published as supplements.

CONCLUSION

A proposed explanation for the ability of radiography to detect the true shape and outline of an incompletely fused nickel enriched resistance spot weld lies in the relative difference in the radiopacity of the materials involved. Since nickel is more radiopaque (absorbs more X-ray energy) than iron, the sharp line of demarcation between the nickel foil and the weld nugget is obviously being recorded on the X-ray film.

Fatigue testing of specimens containing the ring, horseshoe, and intermediate weld nuggets did not affect the internal or peripheral dark line X-ray images. With the exception of the welds from the unstressed test panels, the radiographs included in this report were obtained on samples which had been stressed in fatigue.

On the basis of the test results, it appears that the presence of ring, horseshoe, or intermediate weld nuggets does not have a deleterious effect on the fatigue life of resistance spot weld joints with nickel foil inserts.

Photographic Identification Index

Figure Number	MRG Negative Number	Figure Number	MRG Negative Number
1	M-8530	16	M-9162
2	M-8838	17	M-9161
3	M-8776	18	M-8997
4	M-8837	19	M-9155
5	M-8873	20	M-9156
6	M-8836	21	M-9160
7	M-8771	22	M-9159
8	M-8835	23	M-8989
9	M-8813	24	M-9152
10	M-8826	25	M-9165
11	M-8815	26	M-8990
12A	M-8827	27	M-9153
12B	M-9280	28	M-9164
13	M-8996	29	M-8822
14	M-9158	30	M-8912
15	M-9157		

Figure 1. Reproduction (5X magnification) of a radiograph of five resistance spot welds with a 0.003 inch thick nickel foil insert. The spot weld examined (No. 1) was located in the third row of spots (first from the edge) on the unbroken end of a fatigue specimen (LA32N). Note the dark internal images in the spot weld image. The edge of the doubler sheet is seen at the top of the reproduction.

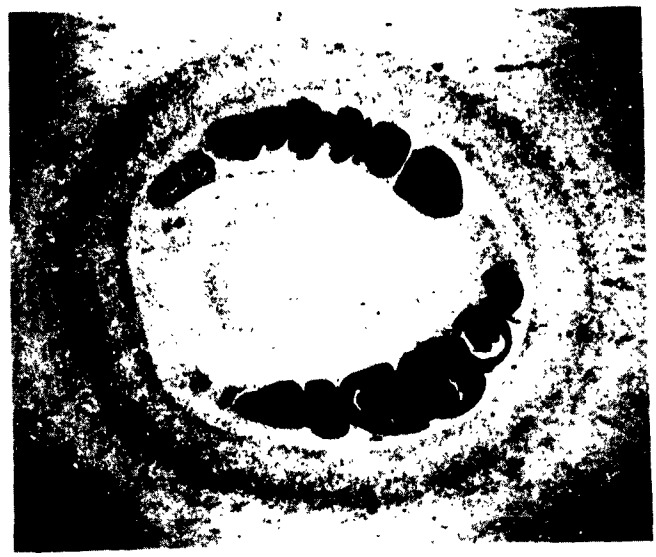


Figure 2. Photomicrograph (30X magnification) of a plan view of the spot weld shown in Figure 1. A view showing ring or "dough-nut" weld was not obtained, however, the light etched internal area along with the islands of fused metal indicate the general form of the ring weld (Etchant: oxalic acid).

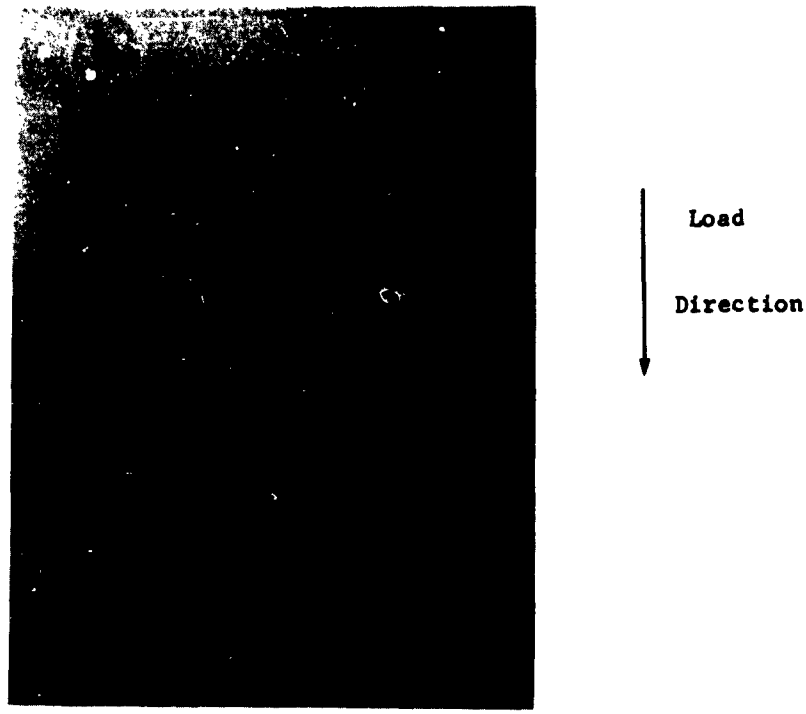


Figure 3. Reproduction (5X) of radiograph of five resistance spot welds with a 0.003 inch thick nickel foil insert. The spot weld (No. 3) examined was located in the third row of spots (second from the edge) on the unbroken end of the same fatigue specimen discussed under Figure 1. Note the internal dark image in this spot weld is identical to the one seen in Figure 1. Positions 1, 2, 3 and 4 correspond to the positions shown in the photomicrograph in Figure 4.

Figure 4. Photomicrograph (30X) of the spot weld cross-sectioned at A-A as shown in Figure 3. This spot weld is an example of the ring or "dough-nut" type (Etchant: Oxalic Acid). Positions 1, 2, 3 and 4 correspond to those shown in Figure 3.

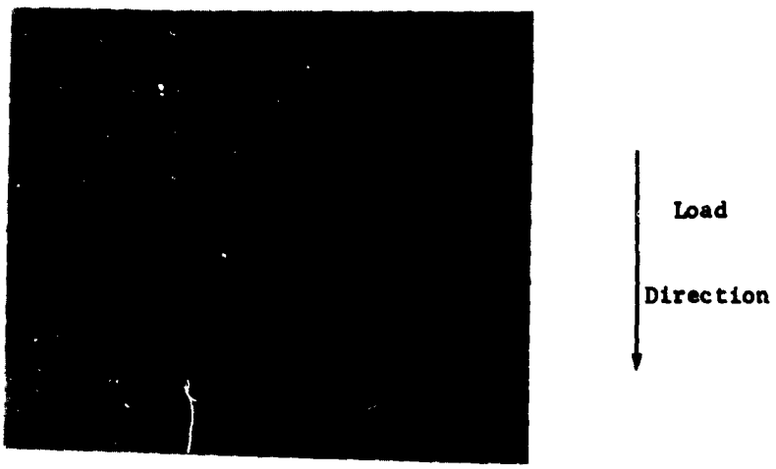


Figure 5. Reproduction (5X) of a radiograph of three spot welds with a 0.003" nickel foil insert. The welds were located in the same specimen (LA32N) discussed under Figure 1. Note that this spot weld image is different than the spot weld images shown in Figures 1 and 3. The spot weld (No. 6) examined was located in the fourth row on the unbroken end and the second weld from the specimen edge.

Figure 6. Photomicrograph (30X) of a plan view of spot weld No. 6 shown in Figure 5. This is a view of the weld nugget in its entire shape and represents an intermediate stage between the ring weld and a complete nugget. Note that the X-ray image represented the true outline of the weld nugget.

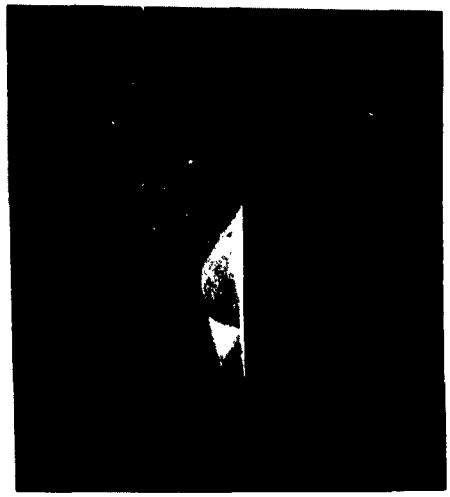


Figure 7. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003" nickel foil insert. This weld was also located in the same specimen (LA32N) discussed under Figure 1. Note that the X-ray image of this spot weld (No. 8) is similar to the images of the spot welds shown in Figures 1 and 3. The section lines indicate the plane of cross-sectioning. The light areas at the top left of the weld are folds of the nickel foil insert. The foil was folded on top of the specimen and not between the 301 sheets. The edge of the doubler sheet is seen at the left side of the reproduction.

Figure 8. Photomicrograph (30X) of the spot weld (No. 8) shown in Figure 7. Note that the plane of cross-sectioning (parallel to the direction of fatigue loading) shows that the weld nugget is not even a complete ring weld. The test skin is the top sheet and the direction of loading is to the left. This spot weld was located in the first row on the unbroken end and is next to the specimen edge. No cracks could be detected in the weld nugget.

Figure 9. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003" nickel foil insert. This spot weld (No. 3) was located in a weld test panel (No. CP61A). The material used to make this panel is identical to the material used to fabricate the fatigue specimens (example, LA32N). This weld panel represents the as-welded condition (not stressed). Note that no internal dark images exist in this reproduction.

Figure 10. Photomicrograph (30X) of a plan view of the spot weld (No. 3) shown in Figure 9. This spot weld is included to show a typical nickel enriched spot weld with good fusion and the typical "marble-cake" structure.

Figure 11. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003 inch nickel foil insert. This spot weld (No. 1) was located in the weld test panel (CP61A) discussed under Figure 9. Note the letter "U" or horseshoe shape of the image.

Figure 12A

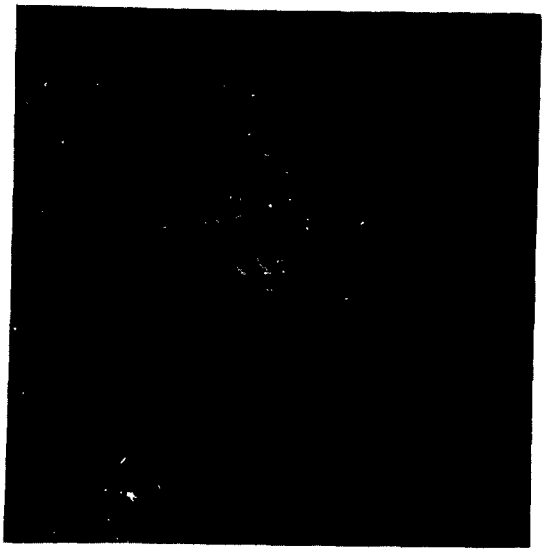


Figure 12B

Photomicrographs (30X) of a plan view of the spot weld shown in Figure 11. The combined area of the fused metal and the light internal area indicates the shape of the nugget in Figure 12A. After an additional 0.003 inch was removed by grinding and polishing, the full shape of the horseshoe nugget was obtained as shown in Figure 12B. This shape correlates with the X-ray image shown in Figure 11.

Figure 13. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003 inch thick nickel foil insert. This spot weld (No. 1) was located in a weld test panel (No. CP61B) and represents the as-welded condition (not stressed). The material used to make this panel (0.011 inch 301) is identical to the one discussed under Figure 9. Note the dark line image on the inner periphery of the light halo image.

Figure 14. Photomicrograph (100X) of the left side of Section A-A of the spot weld shown in Figure 13. This as-polished view shows no presence of a crack or sheet thinning to result in the dark peripheral line image recorded on the X-ray film. Note the line of demarcation between the foil and weld nugget.

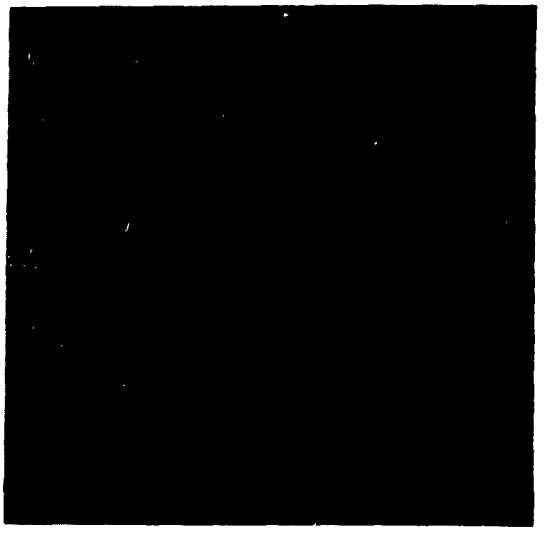


Figure 15. Photomicrograph (100X) of the right side of Section A-A of the spot weld shown in Figure 13. The same comments apply for this section as listed under Figure 14.

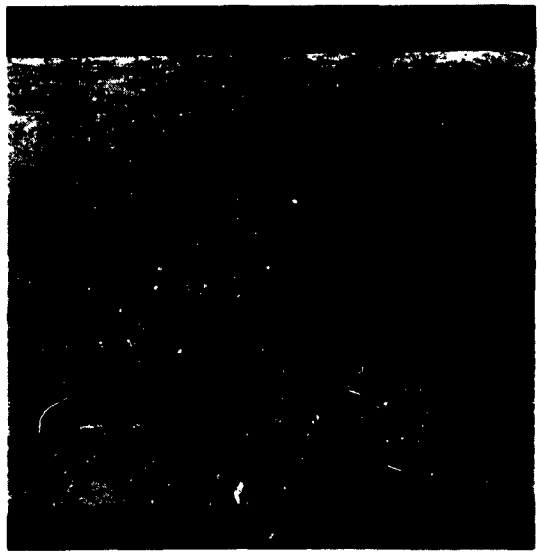


Figure 16. Photomicrograph (100X) of the left side of Section A-A of the spot weld shown in Figure 13. When compared to Figure 14, it is apparent that the dark etching line of demarcation is not a crack, but represents an interface between two metallic phases.

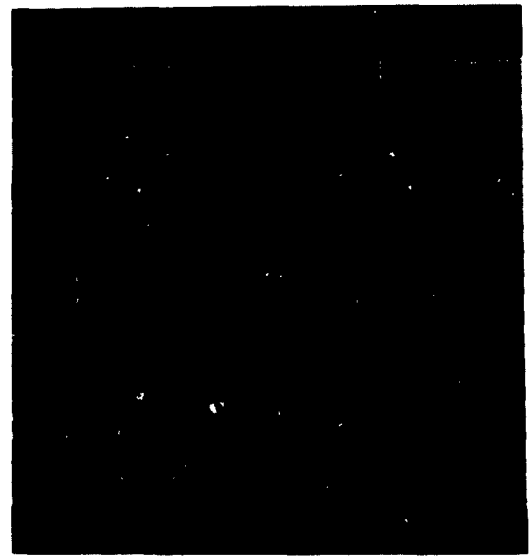


Figure 17. Photomicrograph (100X) of the right side of Section A-A of the spot weld shown in Figure 13. This section illustrates the fact that no crack or sheet thinning exists to cause the recording of the dark peripheral line image.

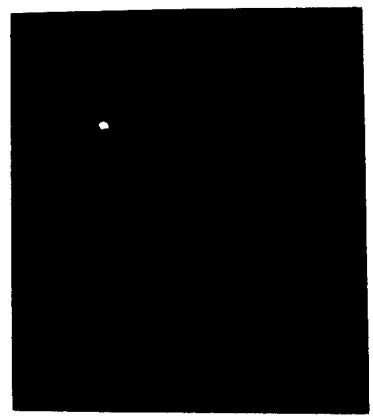


Figure 18. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003 inch nickel foil insert. This spot weld (No. 2) was located in a weld test panel (No. CP61B) and represents the as-welded condition (not stressed). This is the same panel discussed under Figure 13. Note the dark line image at the top inner periphery of the light halo image.

Figure 19. Photomicrograph (100X)of the left side of Section A-A of the as-polished spot weld shown in Figure 18. Note the line of demarcation between the nickel foil and the weld nugget. This section represents the area on radiograph which contains the dark peripheral line image. No cracks are present in this spot weld.

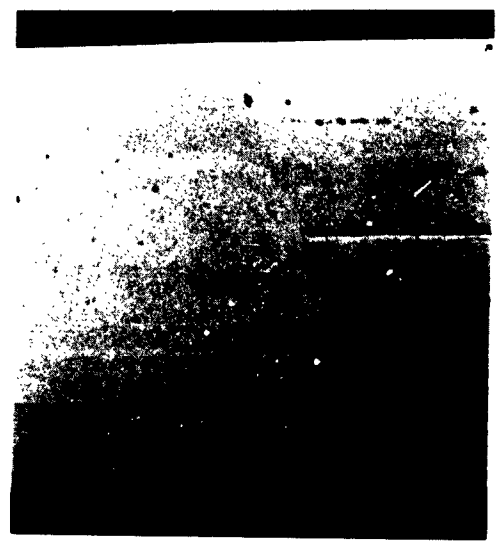
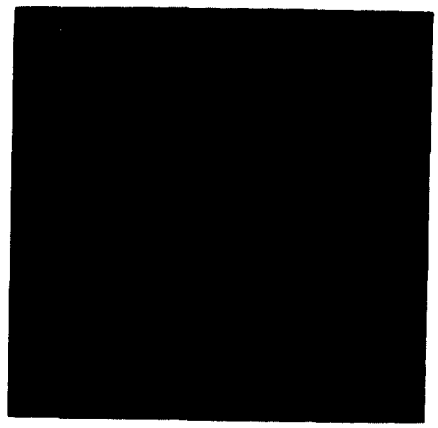


Figure 20. Photomicrograph (100X) of the right side of Section A-A of the as-polished spot weld shown in Figure 18. The section also contains the foil-to-nugget line of demarcation. This section represents the area on the radiograph whichdoes not contain the dark peripheral line image.

Figure 21. Photomicrograph (100X) of the same view shown in Figure 19 except in the oxalic acid etched condition. When compared to Figure 19, it is apparent that the dark etching line of demarcation, as seen above, is not a crack and, therefore, should not be interpreted as such.

Figure 22. Photomicrograph (100X) of the same view shown in Figure 20 except in the oxalic acid etched condition. The same comments in respect to the dark etching line also apply to this section.



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Direction

Figure 23. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003 inch thick nickel foil insert. The spot weld (B) was located in the first row of spots (2nd from the edge) on the unbroken end of a fatigue specimen (No. LB50N), Note the dark line image at the top inner periphery of the light halo image.

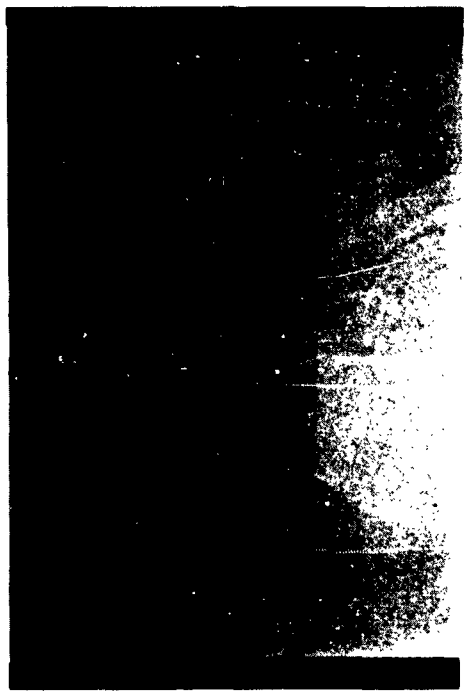


Figure 24. Photomicrograph (100X) of the left side of Section A-A of the as-polished spot weld shown in Figure 23. Note the sheet thinning of the test skin which represents a 2.2% reduction. The foil/nugget line of demarcation can be seen but no crack exists.

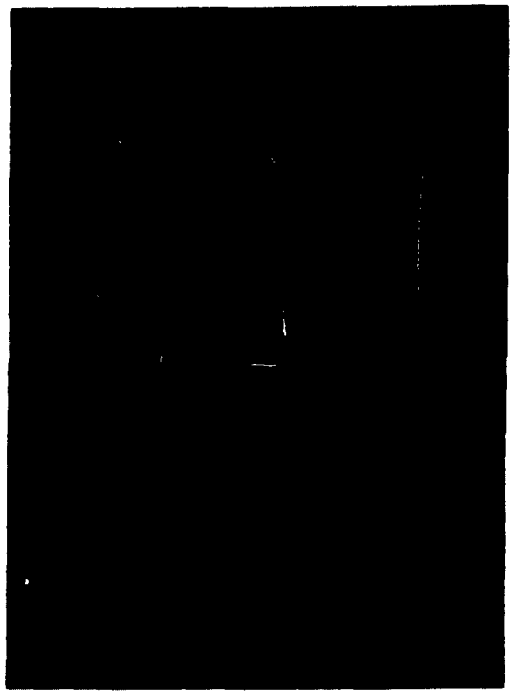
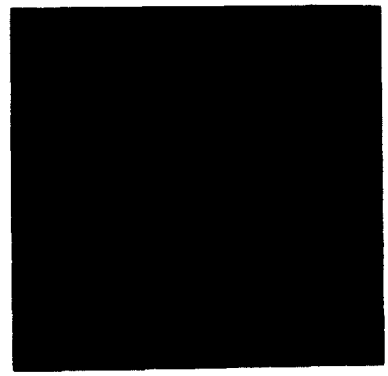


Figure 25. Photomicrograph (100X) of the same view shown in Figure 24 except in the oxalic acid etched condition. Note the foil/nugget line of demarcation is a dark etching phase which may be interpreted as a crack on the X-ray image, but which is an interface between two metallic phases.



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Direction

Figure 26. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003 inch thick nickel foil insert. The spot weld (c) was located in the first row of spots (3rd from the edge) on the unbroken end of a fatigue specimen (LB50N). Note the dark line image located on the inner periphery of the light halo image.

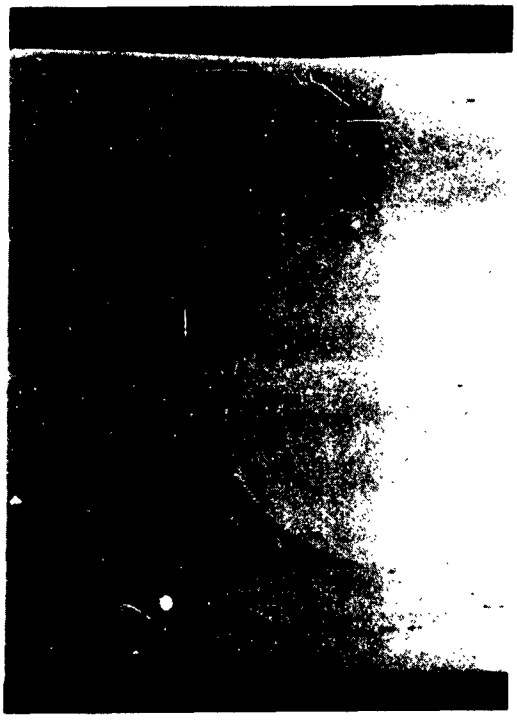

Figure 27. Photomicrograph (100X) of the left side of Section A-A of the as-polished spot weld shown in Figure 26. Note the sheet thinning of the test skin which represents a 2.5% reduction. The foil/nugget line of demarcation can be seen, but no crack exists.

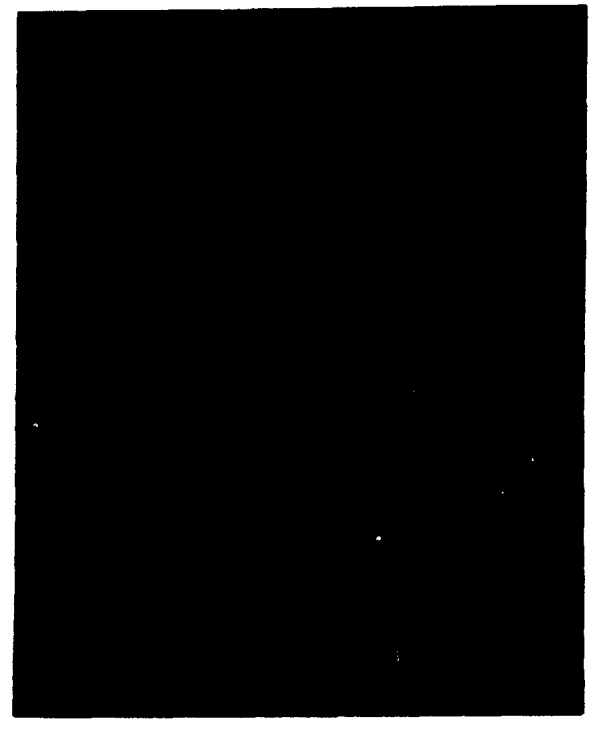

Figure 28. Photomicrograph (100X) of the same view shown in Figure 27 except in the oxalic acid etched condition. Note the dark etching characteristic of the foil/nugget line of demarcation. No crack occurs.

Figure 29. Reproduction (5X) of a radiograph of a resistance spot weld with a 0.003 inch nickel foil insert. This spot weld (No. 2) was located in the first row of spots (1st from edge) on the unbroken end of a fatigue specimen (LB50N). This spot weld obviously contains a crack as based on the long dark line image. The edge of the doubler sheet is at the left of this reproduction.

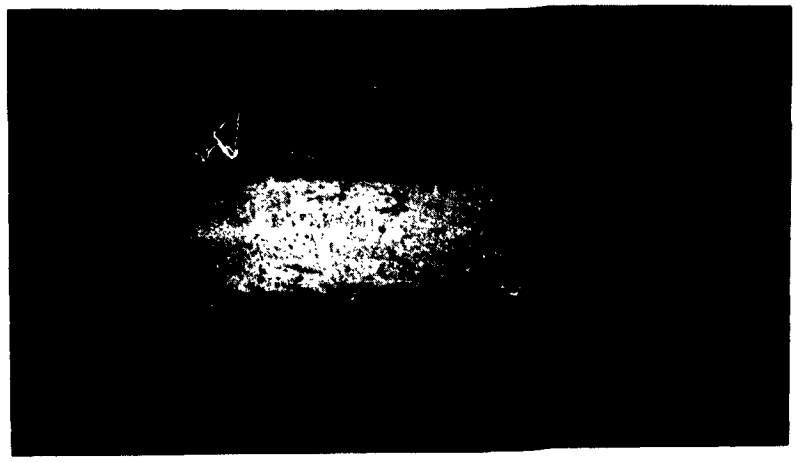

Figure 30. Photomicrograph (30X) of the weld nugget at Section A-A shown in Figure 29. The location of fracture is in the test skin (Etchant: oxalic acid).